

S P E C I F I C A T I O N

NONUNIFORM ROTATIONAL DISTORTION (NURD)

REDUCTION

BACKGROUND OF THE INVENTION

5 **Field of the Invention**

[0001] The invention relates generally to medical imaging, and more particularly to reducing Nonuniform Rotational Distortion (NURD) in medical images.

Background

10 [0002] For purposes of diagnosis and treatment planning, imaging techniques such as ultrasound imaging are commonly used in medical procedures to obtain images of the inside of a patient's body. In intravascular ultrasound (IVUS) imaging, images revealing the internal anatomy of blood vessels are obtained by inserting a catheter with an ultrasound transducer mounted on or near its tip into the blood vessel. The ultrasound transducer is positioned in a region of the blood vessel to be imaged, where it emits
15 pulses of ultrasound energy into the blood vessel and surrounding tissue. A portion of the ultrasound energy is reflected off of the blood vessel wall and surrounding tissue back to the transducer. The reflected ultrasound energy (echo) impinging on the transducer produces an electrical signal, which is used to form an image of the blood vessel.

20 [0003] To obtain a cross-sectional image or "slice" of the blood vessel, the transducer must interrogate the vessel in all directions. This can be accomplished by mechanically rotating the transducer during imaging. FIG. 1 is a representation of an axial view of a rotating transducer 10 mounted on the tip of a prior art catheter 20. The

transducer 10 is coupled to a drive motor (not shown) via a drive cable 30 and rotates within a sheath 35 of the catheter 20. The blood vessel 40 being imaged typically includes a blood region 45 and wall structures (blood-wall interface) 50 and the surrounding tissue.

5 [0004] A cross-sectional image of the blood vessel is obtained by having the transducer 10 emit a plurality of ultrasound pulses, e.g., 256, at different angles as it is rotated over one revolution. FIG. 1 illustrates one exemplary ultrasound pulse 60 being emitted from the transducer 10. The echo pulse 65 for each emitted pulse 60 received by the transducer is used to compose one radial line or "image vector" in the image of the
10 blood vessel. Ideally, the transducer 10 is rotated at a uniform angular velocity so that the image vectors are taken at evenly spaced angles within the blood vessel 40. An image processor (not shown) assembles the image vectors acquired during one revolution of the transducer 10 into a cross-sectional image of the blood vessel 40. The image processor assembles the image vectors based on the assumption that the image vectors
15 were taken at evenly spaced angles within the blood vessel 40, which occurs when the transducer 10 is rotated at a uniform angular velocity.

[0005] Unfortunately, it is difficult to achieve and maintain a uniform angular velocity for the transducer 10. This is because the transducer 10 is mechanically coupled to a drive motor (not shown), which may be located one to two meters from the
20 transducer, via the drive cable 30. The drive cable 30 must follow all the bends along the path of the blood vessel to reach the region of the blood vessel 40 being imaged. As a result, the drive cable 30 typically binds and/or whips around as it is rotated in the blood vessel 40. This causes the transducer 10 to rotate at a nonuniform angular velocity even

though the motor rotates at a uniform angular velocity. This is a problem because the angles assumed by the image processor in assembling the image vectors into the cross-sectional image of the blood vessel 40 are different from the actual angles at which the image vectors were taken. This causes the cross-sectional image of the blood vessel to be distorted in the azimuthal direction. The resulting distortion is referred as Nonuniform Rotational Distortion (NURD).

[0006] Therefore, there is need for an image processing technique that reduces NURD in IVUS images acquired using a rotating transducer

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the concepts being discussed. All illustrations are intended to convey concepts, where relative sizes, shapes and other detailed attributes may be illustrated schematically rather than literally or precisely.

[0008] FIG. 1 is a representation of a rotating transducer of a prior art catheter inside a blood vessel.

[0009] FIG. 2 is a flowchart illustration of an example embodiment of a new image processing method for reducing NURD in IVUS images acquired using a rotating transducer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] Described below is a new image processing method that reduces NURD in IVUS images acquired using a rotating transducer. In an IVUS image of a blood vessel, the blood inside the blood vessel and the tissue surrounding the blood vessel have texture, which appear as speckles in the IVUS image. The blood typically has a fine image

texture and the surrounding tissue has a course image texture. For an IVUS image taken with a transducer rotating at a uniform angular velocity, the image texture of the blood and the surrounding tissue should be fairly consistent throughout the image. However, when the transducer rotates at a nonuniform angular velocity, the image texture in the

5 blood and the surrounding tissue becomes nonuniform. In regions of the image where the angular velocity of the transducer speeds up, the image texture becomes compressed in the azimuthal direction. In regions of the image where the angular velocity of the transducer slows down, the image texture becomes expanded, e.g., smeared out, in the azimuthal direction.

10 **[0011]** Therefore, the degree of texture compression/expansion in the image yields information about the relative angular velocity of the transducer during imaging. Using this principle, the new imaging processing method corrects for NURD in an image, as explained further below.

[0012] Turning now to FIG. 2, an example embodiment of a new image

15 processing method for reducing NURD will be described. In step 210, an image processor receives an input image comprising a plurality of image vectors, e.g., 256 vectors. The image vectors are mapped onto angles in the image based on the assumption that the image vectors were taken at uniformly spaced angles. Each of the image vectors further comprises a plurality of pixels. The value of each pixel corresponds to the

20 amplitude of a received echo pulse that is reflected back to the transducer from a certain angle and radial distance with respect to the transducer. The values of the pixels may be scaled according to a gray scale and/or a color scale.

[0013] In step 220, a spectral measure of texture around each pixel is computed in the azimuthal direction. This may be accomplished by performing a one-dimensional Fourier transform on a set of pixels within a weighted window centered at the pixel. The Fourier transform may be performed using standard signal processing techniques known to those of ordinary skill in the art. The Fourier transform for each pixel produces a frequency spectrum that contains local textural information for the pixel.

[0014] The weight of the window used in the Fourier transform may be computed using the following equation:

$$Weight = e^{-\left(\frac{n - \left(\frac{w+1}{2}\right)}{\chi}\right)^2}$$

where w is the width of the window, χ determines the drop off rate of the weight from the center of the window, and n is incremented from 1 to w . As an example, the width w may be 16 pixels and χ may be 4.

[0015] In step 230, the mean frequency of the Fourier transform for each pixel is computed. The mean frequency for each pixel provides a textural measure for the pixel with higher values indicating textural compression and lower values indicating textural blurring.

[0016] In step 240, for each image vector, the average value of the mean frequency for the pixels in the image vector is computed. The average frequency value for each image vector correlates with the relative angular velocity for the transducer at the image vector. A high average frequency value indicates a relatively high angular velocity for the transducer at the image vector and a low average frequency value indicates a relatively low angular velocity for the transducer at the image vector. For a

transducer rotating at a constant angular velocity, the average frequency values for the image vectors is noted to be fairly constant.

[0017] In step 250, the integral of the average frequency values for all the image vectors is computed with the integral normalized to a value of 2π radians, which is the angle of one revolution of the transducer. In step 260, an estimate of the actual angle for each image vector is computed using the running value of the normalized integral at the image vector. This estimated angle for each image vector takes into account the fact that image vectors are not taken at uniformly spaced angles. In step 270, each image vector is remapped to its respective estimated angle to produce a NURD corrected image. In other words, NURD is reduced or eliminated by deriving an estimated angle for each image vector and using that estimated angle instead of the inaccurately assumed uniformly spaced angle.

[0018] The value of the width w and χ used to compute weight of the window in step 220 may be optimized through normal experimentation. For example, a phantom, e.g., made of rubber, having a known cross-sectional profile may be imaged using a rotating transducer. The NURD algorithm may then be applied to the image of the phantom while adjusting the values of w and χ until the NURD corrected image exhibits the least amount of NURD.

[0019] In the foregoing specification, the invention has been described with reference to a specific embodiment thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention. For example, the reader is to understand that the specific ordering and combination of process actions shown in the process flow diagrams

described herein is merely illustrative, and the invention can be performed using different or additional process actions, or a different combination or ordering of process actions.

As another example, features known to those of skill in the art can be added to the embodiment. Other processing steps known to those of ordinary skill in the art may

5 similarly be incorporated as desired. Additionally and obviously, features may be added or subtracted as desired. Accordingly, the invention is not to be restricted except in light of the attached claims and their equivalents.